Monte Carlo Simulation of a Neutron Detector (BF_3 – ^3He)

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1. Introduction

In this work we have studied the neutron detection efficiency for neutron detector based on a set of BF_3 and ^3He proportional counters, by means of Monte Carlo simulations with MCNPX. The neutron energy ranges from 0.1 eV to 10 MeV. The result shows a detection efficiency about 0.4. This neutron detector has been inspired on the NERO (Neutron Emission Ratio Observer) detector from the National Superconducting Cyclotron Laboratory at Michigan State University.

2. Description

2.1 Assembly

The assembly of the neutron detector is formed by three concentric rings of proportional counters embedded in a 60cm x 60cm x 80cm polyethylene matrix. A centred 22.4 cm diameter hole crosses the matrix to allow the entrance of the neutron beam to the assembly. Each ring of proportional counters has the following characteristics:

Ring A: Distance to the centre of the matrix, 13.6 cm. 16 ^3He proportional counters with an internal diameter of 2.5 cm. The walls material is stainless steel with a thickness of 0.05 cm and a length of 80 cm. Gas pressure about 4.1 bar.

Ring B: Distance to the centre of the matrix, 19.2 cm. 20 BF_3 proportional counters with an internal diameter of 5.08 cm. The walls material is stainless steel with a thickness of 0.05 cm and a length of 80 cm. Gas pressure about 0.7 bar. The boron is ^{10}B enriched at 99%.

Ring C: Distance to the centre of the matrix, 24.8 cm. 24 BF_3 proportional counters with the same characteristics as the counters of the ring B.

The external faces of the polyethylene matrix are covered by a layer of B_4C (1 cm thick) to minimize the neutron background. See Figure 1 and Figure 2

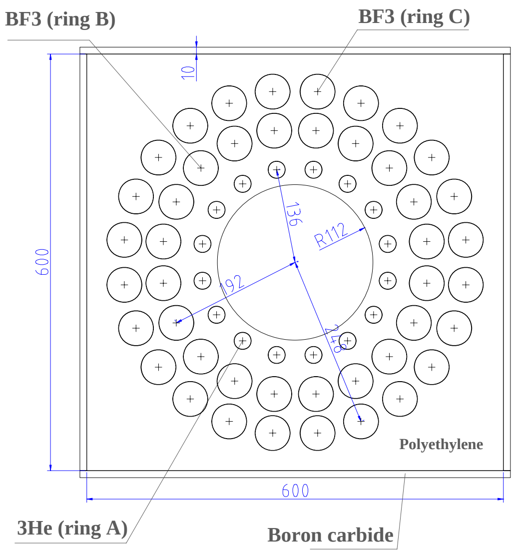

Figure 1. Dimensions of the neutron detector assembly

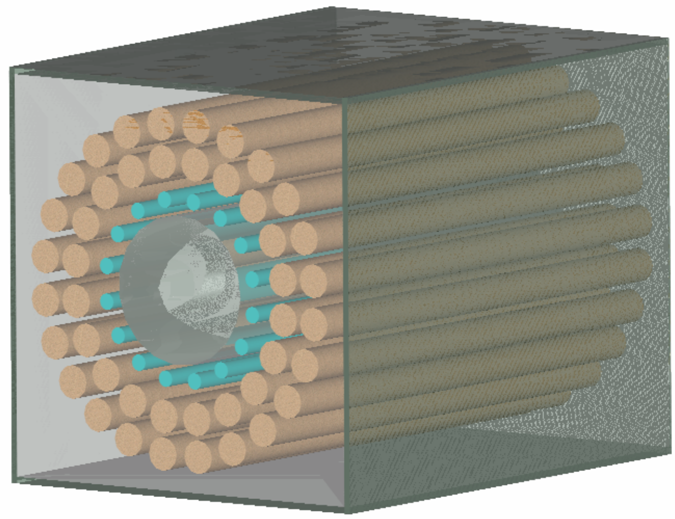

Figure 2. Three dimensional view of the assembly geometry. First ring (blue) ^{3}He proportional counters; second and third rings (orange) BF_3 proportional counters and polyethylene matrix (grey).

2.2 Simulation

The geometry of the neutron detector assembly has been modeled for MCNPX 2.4.0. We have located an isotropic point neutron source at the centre of the matrix, inside the central hole. The tallies employed are *current integrated over a surface* (Type 1), with selection of direction (*cosine multiplied card*) to count the neutrons crossing the surfaces that define the proportional counters walls. The information extracted from the tallies give us the number of neutron interactions produced inside the detectors.

We have calculated the neutron efficiency for the proportional counters (*detector effciency*), located at each ring, η_A, η_B, $\eta_{C,}$ (eq. 1). Also we have calculated the total neutron efficiency for the neutron detector assembly (*detection efficiency*), η_{Total} (eqs. 2 and 3). For each neutron energy and each proportional counter, we have counted the number of neutrons emitted by the source, n_{source}, the number of incident neutrons, n_{in}, to the external wall (proportional counter), and the number of incident and outgoing neutrons to the internal wall, n^*_{in}, and n_{out} respectively. The number of neutrons absorbed inside each counter is $n_{abs}=n^*_{in} - n_{out}$.

$$\eta_{\text{A,B, or C}} = \frac{n_{\text{abs(A,B, or C)}}}{n_{\text{in}}} \qquad \textbf{eq. (1)}$$

$$\eta_{\text{Total(A,B, or C)}} = \frac{n_{\text{abs(A,B, or C)}}}{n_{\text{source}}} \qquad \textbf{eq. (2)}$$

$$\eta_{\text{Total}} = \eta_{\text{Total,A}} + \eta_{\text{Total,B}} + \eta_{\text{Total,C}} \qquad \textbf{eq. (3)}$$

We have simulated the transport of 10^6 neutrons for 9 different monoenergetic sources: 0.1 eV, 1 eV, 10 eV, 100 eV, 1 keV, 10 keV, 100 keV, 1 MeV, and 10 MeV.

3. Results

The results obtained for the detector efficiency and detection efficiency are shown in figures 3 and 4 respectively. Also in table 1 are shown the numerical values. As can be seen, the global efficiency varies from 0.444 to 0.489 for a wide range of energies (0.1 eV to 1 MeV), and decreases to 0.2 for energies up 1 MeV and below 10 MeV.

Energy (eV)	Detector efficiency			Detection efficiency			
	η_A	η_B	η_C	$\eta_{Total,A}$	$\eta_{Total,B}$	$\eta_{Total,C}$	η_{Total} (A+B+C)
0.1	0.238	0.332	0.331	0.280	0.130	0.035	0.444
1	0.219	0.327	0.328	0.271	0.149	0.041	0.462
10	0.197	0.316	0.321	0.253	0.168	0.049	0.470
10^2	0.178	0.302	0.312	0.237	0.182	0.058	0.477
10^3	0.161	0.284	0.297	0.221	0.192	0.067	0.481
10^4	0.145	0.265	0.281	0.206	0.202	0.077	0.484
10^5	0.125	0.228	0.249	0.182	0.211	0.096	0.489
10^6	0.093	0.147	0.165	0.123	0.196	0.136	0.455
10^7	0.048	0.071	0.084	0.035	0.082	0.084	0.201

Table 1. Intrinsic efficiency of the proportional counters at each ring, and the total efficiency of the neutron detector, considering each ring individually and considering the whole rings.

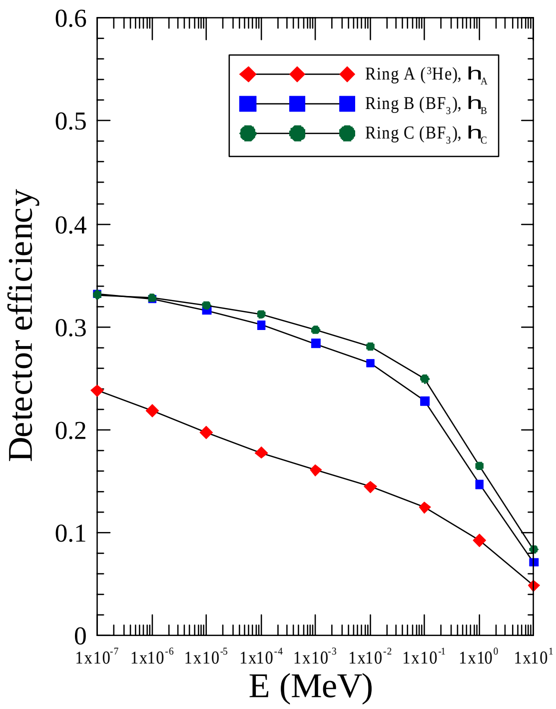

Figure 3. Detector efficiency. This efficiency measures the ratio of the absorbed neutrons divided by the number of incident neutrons to a proportional counter.

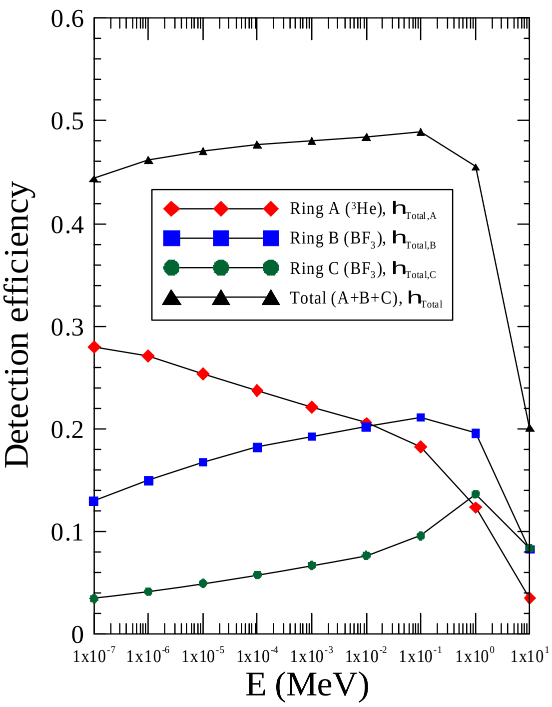

Figure 4. Detection efficiency. This efficiency measures the ratio of the absorbed neutrons divided by the number of neutrons emitted by a neutron source.